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The development of Conservation Agriculture in Australia—Farmers as innovators

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Abstract

The Australian story of farmer innovation in Conservation Agriculture reveals a complex interplay of policy, economics, science, and farming. Farmer experimentation with Conservation Agriculture began in the 1960's and has continued to this day where around 80%-90% of Australia's 23.5 million hectares of winter crops are now grown using Conservation Agriculture principles. This remarkable achievement is the result of both sustained investment in agricultural research and development and farmer innovation. Australian economic settings and science policies have encouraged and facilitated farmer participation in the Conservation Agricultural innovation system. Australian farmers have embraced Conservation Agriculture because it has met their needs, maintaining productivity and profitability in the face of declining terms of trade, and sustainably intensifying production with enhanced environmental outcomes. Drawing on individual farmer case studies, the specific strengths of farmer innovation are identified and the enabling conditions necessary for farmer innovation to flourish are discussed.

Key Words: Conservation Agriculture, No-till, Farmer associations, Farmer innovation, Precision agriculture

1 Introduction

Australia is an ancient landscape with highly weathered and largely infertile soils. By virtue of the continent's location in the mid-latitudes of the southern hemisphere, the climate over most of the continent is comparatively dry and highly variable from year to year. These characteristics, old, highly weathered, infertile soils, and low and variable rain fall, have shaped Australian agriculture, driving a relentless pursuit of innovation to remain productive, profitable, and sustainable. Drought is a significant and regular characteristic of Australian agriculture, and many land management strategies are geared around minimising the risks associated with low and irregular rainfall, i. e. maximising crop yield per millilitre of rainfall. Thus, the attractiveness of Conservation Agriculture to Australian farmers is due in large part to improved soil water availability under this system.

Australian agriculture has a relatively short history compared to most major agricultural countries. European settlement occurred only in 1788, and agriculture expanded slowly at first, reaching 2 million hectares by 1900, and then more rapidly from 1960 to 1990 to reach around 23.5 million hectares today. Over time Australia has become a major agricultural exporting country, key commodities including beef, wheat, sugar, wool, barley, dairy, and wine. Around 60%-70% of agricultural production is exported (the domestic market is based on a population of only 23.3 million people), thus exposing Australian farmers to fluctuating and uncertain world commodity prices. Due to this reliance on international trade, Australia is a strong advocate for free trade, arguing against government subsidies, tariffs and quotas, including agricultural produce. Today, Australian farmers are among the least subsidised in the world.

In summary, the salient features of Australian rain-fed agriculture are low and variable rainfall, old and infertile soils, exposure to international commodity prices, combined with a low level of economic support from

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the government. This challenging production environment has spawned a unique agricultural research and development funding system that entrenches farmers' interests and influence as both actors and beneficiaries of agricultural innovation. More recently, non-government farmer organisations have become proactive in the innovation process, further enhancing research relevance to farmers' needs.

Conservation Agriculture (CA), sometimes described as No-Till, Reduced Tillage, or Stubble Retention, has been shaped by these challenges. Today, a significant majority of Australian farmers grow winter cereals using Conservation Agriculture (CA) principles[3]. These principles include minimum or zero tillage, partial or full retention of crop residues to maintain soil cover, and rotation of cereals, oilseeds and pulses (legumes) over time. What lessons can be extracted from this experience? How transferable is the Australian experience? This paper highlights the critical role of farmers in the agricultural innovation system; farmers add value to institutional research and development by adapting, adopting, and disseminating research findings and new technology. Farmer-to-farmer learning has been a key feature of the adoption of CA in Australia. The paper makes explicit the varied roles played by farmers, government policies and institutions that have supported this innovation, the emergence of organisations such as no-till farmer associations, and importantly the contributions of individual farmers.

2 A brief overview of Conservation Agriculture in Australia

The following section summarises Conservation Agriculture in Australia, highlighting both the key developments in science and technology underpinning CA, as well as key developments in the institutions and organisations that have facilitated farmer participation in the innovation system (Fig. 1). Further information is available in recent reviews of Australian rain-fed agriculture (Carberry et al., 2011; Kirkegaard et al., 2011; Hochman et al., 2013).

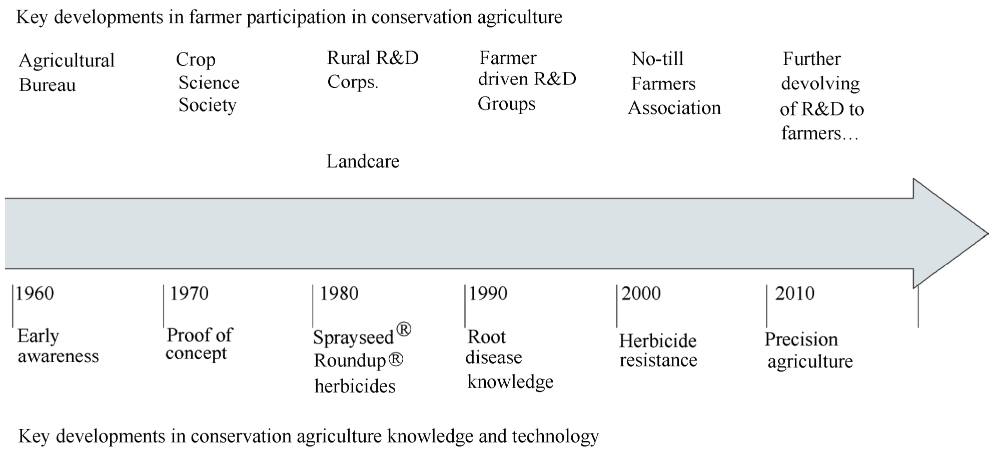

Fig. 1 Key events in the evolution of farmer involvement in Conservation Agriculture innovation in Australia

The participation of Australian farmers in Conservation Agriculture research and development is a prime example of farmer participation in the agricultural innovation system more generally. Early innovation in agriculture was promoted by the Agricultural Bureau movement which was established in 1888. Agriculture Bureaus were formed as local rural community organisations and continue to this day in some districts, creating awareness and promoting improved farm management. In South Australia the Crop Science Society was formed in 1975 and continues to be an active forum for farmer-scientist communication, providing valuable insights in both directions. In the mid 1980s the Australian government established the Rural Research and Development Corporations (e.g. GRDC[4], MLA, etc.), establishing research funds contributed from levies on the farm-gate value of production and matching farmer contributions with government funds. These rural R&D corporations feature farmer representation on their executive boards, and farmer representation on regional committees, ensuring a strong farmer perspective in strategic policy and operational decisions. The mid 1980s also saw the

[3] The principles of Conservation Agriculture were ultimately defined by FAO (Friedrich et al., 2009).

[4] GRDC, Grains Research and Development Corporation; MLA, Meat and Livestock Australia.

establishment of Landcare, a community based organisation devoted to integrating production and conservation goals in agriculture. During the 1990s, a number of community based farmer organisations were established (for example Kondinin, Birchip) providing a new focus on delivery of agricultural research that was relevant to local needs. More recently, several no-till farmer associations have been established to focus specifically on local innovation of CA systems (Fig. 1 and Table 1). At the same time that farmer involvement in innovation was expanding, perhaps because of it, traditional state government services in research and extension were being withdrawn.

Table 1 Examples of research and development projects from Australian No-Till farming associations.

Project Title	Farmer Group	Funding Source
Promoting Sustainable Cropping Practices for Farmers in Dryland Agriculture	Conservation Agriculture Alliance of Australia & New Zealand (CAAANZ) http://www. caaanz. org. au/	Commonwealth Department of Agriculture Fisheries & Forestry
Dry seeding into crop residues	Western Australian No-Tillage Farmers Association (WANTFA) http://www. wantfa. com. au/	Grains Research Development Corporation
Long Term No Tillage farming systems	WANTFA	Grains Research Development Corporation
Community FarmlinkX – Productive pollution free agriculture – pathways to rural and urban coexistence.	South Australian No-Till Farmers Association (SANTFA) http://www. santfa. com. au/	Commonwealth Department of Agriculture Fisheries & Forestry
Struvite as a Phosphorus Replacement.	SANTFA	Zero Waste SA
Understanding the behaviour of water in dryland soils	Victorian No-Till Farmers Association (VNTFA) http://vicnotill. com. au/	Landcare
New & Emerging Solutions to Grazing No-Till	VNTFA	Grains Research Development Corporation
Farmers Helping Farmers-Sharing the Knowledge of No-Till	VNTFA	Commonwealth Department of Agriculture Fisheries & Forestry
Enhancing Community Education In Conservation Agriculture	Conservation Agriculture and No-Till Farming Association (CANFA) http://www. confarming. org. au/	Commonwealth Department of Agriculture Fisheries & Forestry
Working with farmers to increase soil carbon	CANFA	Central West Catchment Management Authority
Study tour of Argentinean zero-till machinery and systems	CANFA	Grains Research and Development Corporation
Professional Development for Farmers using Information Communication Technology ("webinars")	Conservation Farmers Inc. (CFI) http://www. cfi. org. au/	Commonwealth of Australia FarmBis program
The evaluation of bio-degradable polymer films for use in agriculture	CFI	Cooperative Research Centre for Polymers

Australian farmers began the transformation to Conservation Agriculture (CA) in response to soil erosion by wind and water. Australian cropping soils are highly variable in their genesis and inherent fertility. The major soil types (Australian Soil Classification, http://www. clw. csiro. au/aclep/asc_re_on_line/soilhome. htm; and corresponding Soil Taxonomy Order) include; Sodosols (Alfisols, Aridisols), Calcarosols (Aridisols, Alfisols), Vertisols (Vertisols), and Rudosols (Entisols, salic Aridisols).

The emerging paradigm of reduced tillage and retention of crop residues to maintain soil cover has been a major transformation in Australian rain-fed agriculture over the past 40-50 years (Thomas et al., 2007). In cropping terms, "Conservation" when applied to agriculture began by challenging the need for continual tillage of the soil to create planting conditions. It proposed that in well maintained soils most tillage practices were not only unnecessary, but over time, destructive to the soil environment. Crop residues after harvest were retained to replenish and protect the soil from the elements, and a range of crops were grown to minimise pest and disease outbreaks. It was a step towards a more sustainable production system. For industrial agriculture, reducing tillage meant a significant reduction in energy demand and soil erosion. More recently there has been strong farmer interest in the soil, and how compaction from heavy machinery can be reduced to retain soil structure and maintain the many soil organisms that support plant growth.

The term "Conservation Agriculture" was seen as recognition that the input resources to agriculture are not limitless. It applies equally to all areas of agriculture in all parts of the world, but in the context of this paper it applies to industrial crop production in the more fragile, semi-arid zones of Australia. The cereal producing region of Australia is vulnerable to extremes of weather, and high variability in rainfall. This is expected to continue, or perhaps intensify, under future climate change.

Today, the Australian grains industry generates around 45 million t of grain depending on seasonal conditions. This production is located within the 300 to 800 mm inland rainfall zone from Central Queensland to Western Australia. Much of this production occurs on light soils, with limited water holding capacity. Researchers and farmers realised soil water management was critical for crop production, and CA practices were believed to increase crop water use efficiency (WUE=grain yield / water use, where water use consists of in-crop rainfall and stored soil water at the time of sowing). Conservation agriculture acted on WUE in several ways; reducing evaporation by maintaining cover and reducing tillage, and increasing infiltration by improving surface soil structure and by providing preferential flow via standing stubble. A highly significant consequence of CA is the value added from earlier sowing, thereby reducing moisture loss to weeds and/or evaporation. Related improvements in crop nutrition, disease management, and integrated weed management paralleled the development of CA, and contributed to the overall CA package that was meeting farmer requirements for increased resource use efficiency in the face of declining terms of trade.

The early period of CA began in the late 1960s with a number of working visits to the US and Canada by teams of farmers and government officers (Fig. 1). In Queensland, the major issue was water erosion, and in 1969 Graham Schwartz and farmer Hector Tod went to the United States to investigate soil conservation management systems. Following the trip, the Queensland Department of Primary Industries (QDPI) imported stubble handling machinery donated by John Deere for testing in Queensland. A machinery testing program was developed across 3 regional areas consisting of department officers and farmers working to evaluate a range of machinery including blade, sweep and chisel ploughs, tine design and configuration, points and press wheels. The research was carried out on farms with support from farmer committee members. Local manufacturers such as Napier Bros., Janke Bros. and Gyral began building and testing various versions to develop improved no-till planters. Another study tour was conducted in 1976 to North America, involving department officers and farmers, and in their report they recommended that research should be directed into no-tillage and double cropping systems. In 1979, herbicide manufacturers, ICI and Monsanto, became involved with herbicide trials for replacing tillage as the means of weed control. This greatly facilitated the increased use of reduced tillage.

On the light sandy soils of Western Australia, the most important catalyst for change was the increasing number of dust storms across the cereal belt. Farmer and author Bill Crabtree recounts the dramatic impression this left on him as a child. His involvement with the Department of Agriculture brought him into contact with no-till research, and he typified a generation of young farmers who began to question the sustainability of current practices and saw no-till systems as the way forward, and who actively tested and promoted these concepts on their farms (Crabtree, 2010). However, no-till systems in Western Australia did not appreciably increase until the 1990s when farmers came to appreciate the moisture retention benefits of CA on demonstration farms. South Australian farmers had strong connectivity with Western Australian farmers due to similar light soils and similar weather patterns. Local researchers and farmers were exploring reduced and no-till systems, and very quickly followed the WA example.

Droughts during 1982-1983 and early 1990s provided strong stimuli for the uptake of CA. Pioneer farmers such as Robert Ruwoldt and Peter Walsh in Victoria were not only demonstrating better results on their farm, they were also proactive in sharing how they made the change. This was a key factor in providing confidence to neighbouring farmers.

The time line of adoption of no-till in Australia is shown in Fig. 2 (Llewellyn and D'Emden, 2009). Although there are important differences between States, mainly reflecting different times of introduction of no-till technology, the pattern of adoption is strikingly similar with most States approaching a plateau of adoption around 80%-90% by 2008. An important feature is the long lead time between first introduction of no-till systems (1960-1980) and the commencement of a period of rapid adoption (late 1980s to 2000). This long lead time represents a period of scientist and farmer experimentation, refining the system to a point (late1980s) where farmers had confidence in implementing the new system, leading to rapid diffusion and adoption. During this period of uptake, the system continued to evolve, for example responding to herbicide resistant weed populations or implementing Precision Agriculture technology.

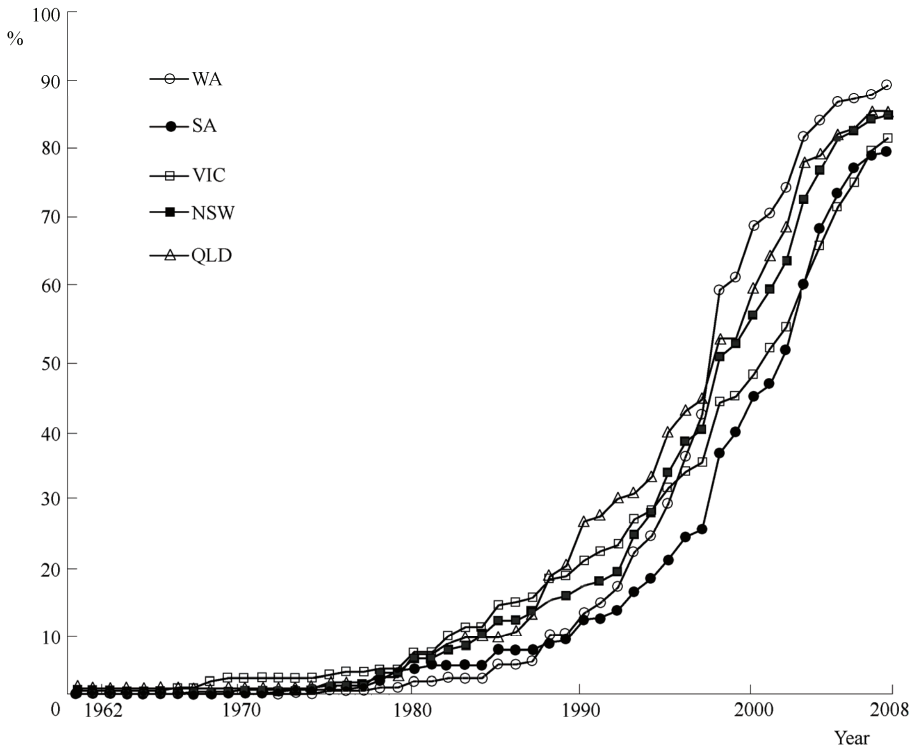

Fig. 2 Cumulative adoption (% of survey respondents) of No-Till cropping systems[5] in winter cereal growing regions of southern Australia (NSW, New South Wales; QLD, Queensland; SA, South Australia; VIC, Victoria; WA, Western Australia). Survey conducted in 2008, number of respondents equals 1, 172 (Llewellyn and D'Emden, 2009)

The scale of experimentation is important to farmers, particularly for adoption of research results. Field trials need to be at farm scale using farm-scale equipment to increase relevance and give farmers a measure of confidence in adopting a new practice (Fig. 3). Farmers are understandably reluctant to adopt results from small plot experiments and translate these across a field. Farmers identify potential financial risks in making that adaptation on their own, so farmer managed demonstrations using commercial equipment and outlining the economic benefit at appropriate scales are important features of applied research and development. It is important to note that departmental officers often worked alongside farmers in establishing and running demonstration trials.

The long term benefit of reduced soil loss remains an important feature of CA, but a more immediate advantage is that CA is a climate resilient farming system. A key feature of CA that continues to attract Australian farmers is the retained soil moisture benefit that results in increased yield, more timely planting opportunities particularly in dry years, and reduced risks associated with low and uncertain rainfall. The value of soil moisture retention under CA is shown in Table 2.

Such a transformational change in cropping systems presented many challenges in the early stages, increasing farmer demand and need for demonstration farms. In some areas, farmers established local no-till research and development groups to coordinate local research and demonstration programs. This was important as they could experience firsthand the cause and effect of different cropping systems and what these might mean to their farm, considering that many farmers had different soil conditions and machinery. Local machinery manufacturers realised the business opportunity and were keen to support this change by demonstrating their own modified machinery. The development of no-till seeding machinery was principally driven by farmers and manufacturers.

[5] A relatively broad definition of no-till seeding was used in the study based on seeding with low soil disturbance and no prior cultivation. No-till was defined early in the questionnaire as including sowing techniques using either no-till with disc machines, knifepoints, super-seeder, or inverted-t equipment, provided that they were used with no prior cultivation (Llewellyn & D'Emden, 2009).

Fig. 3 A typical farmer field day during the farmer implementation and diffusion stages of the innovation cycle (Photo courtesy of Conservation Farmers Incorporated)

An obvious consequence of reducing tillage was changed weed population dynamics, and integrated weed management has become a major concern. Initially, this was approached with various mixes of herbicides to cover a variety of weed spectrums, requiring increased technical support. The availability of highly effective broad-spectrum herbicides, such as Glyphosate (RoundUp^{TM}) from Monsanto and Paraquat Diquat (SpraySeed^{TM}) from ICI, was well timed to meet demand for reduced tillage weed control (Fig. 1; Phillips and Young, 1973). The herbicide companies were quick to see the opportunity and supported a range of demonstration trials across the industry. Although initially quite expensive, the cost-benefit ratio proved efficacious enough that many pioneer farmers saw the potential and adopted the technology. The demonstrated combination of potentially larger profits and reduced technical barriers at a farm scale resulted in more farmers changing their practices (Llewellyn and D'Emden, 2009). Later, herbicide resistant weed populations created new challenges, requiring significant research and farmer innovation in integrated weed management (Walsh and Powles, 2007).

Table 2 Comparison of yield and profit from two tillage systems at two locations in Queensland from a trial conducted by the then Queensland Department of Primary Industries (QDPI) and presented to farmers in the publication *Opportunity Cropping* 2nd *Edition* produced by Conservation Farmers Inc. 1998

Tillage system comparison	Biloela 1989-1992 Wheat yield (t ha^{-1})	Goondiwindi 1989-1992 Wheat yield (t ha^{-1})
Conventional Cultivated	2.5	1.6
No-Till	3.4	2.2
Relative annual benefit value of No-Till in today's dollar value (AUD) (\$220 t^{-1}) for a 1,000 ha property	\$198, 000	\$132,000

Drought had a significant influence on effecting change. Many farmers during droughts noticed differences between their fields and those of innovative farmers, and this led them to investigate new practices. Farmers in drought affected areas were often the most motivated to change or experiment with these new ideas. Once a concept such as reducing tillage to improve moisture retention was established, farmers went about experimenting with their own modifications, pushing the boundaries even further. This is still a common phenomenon, whether it involves press wheel modification or a different version of a shielded sprayer. More recently, farmers are experimenting with conservation crop rotations where a crop is planted within inter-row into a harvested crop. The concept of inter-row cropping has been known for some time and from this theoretical framework, farmers are increasingly experimenting with several overlapping rotations as a component of integrated weed management. Once they are convinced, innovative farmers take the results and adapt new technology or systems in their own way, often involving commercial agronomists and agricultural input suppliers.

The advent of farmer groups (Fig. 1) was the result of farmers wishing to change practices (such as reducing tillage), but facing a degree of uncertainty in making the transition. The financial repercussions of crop failure for farmers changing practices can be substantial, with the additional embarrassment of failure for all to see. Farmers organised local groups as the means of pooling the cost of facilitators, and as a way of controlling the conditions of the process. Groups of peers allowed open sharing of successes and failures. Over time, some of the smaller groups coalesced into more formal, larger groups where farmer experiences were shared in meetings and through articles.

3 Farmers as innovators

The process of farmer innovation is characterised by a complex web of influences that evolve with time. Typically, farmers are influenced by extension agronomists, but agronomists are also strongly influenced by innovative farmers who in turn influence other farmers. The following real world examples illustrate a form of Action Research as described by O'Brien (1998) and later by Dick (2009), conceptualised in Fig. 5. As shown, farmers may adopt a research concept, test and refine it in the field to find in-situ solutions that are passed on to others to do likewise, which in turn may influence other actors to extend the process (O'Brien, 1998; Dick, 2009). Although simple in concept, it is a complex human process and it is difficult to attribute direct influence. Farmers often obtain information from various sources before making a decision, and the adaptation process often occurs over many cropping seasons. Furthermore, there are often generational influences and a family context in the process. The following case studies from across Australia illustrate the diversity of farmer experience with Conservation Agriculture innovation.

3. 1 *Victoria* (*farmer to farmer*)

In Victoria, farmer-to-farmer learning and the sharing of information began with a core group of farmers who experimented with no-till following the 1982 drought which saw significant wind erosion in the state［the progress of this small number of farm families in the process of change is described on their association website (Victorian No-Till Farmers Association, 2013)］.

The Ruwoldt family on Glenvale Downs at Minyip is one of the pioneers of no-till in Victoria. The catalyst for change was the highly visible dust storms of the time, which were removing the exposed cropping soils following cultivation and stubble burning. The process of change to Conservation Agriculture happened over many years and it took another drought in 2006-2007 to highlight the value of change to other neighbouring farmers. Robert Ruwoldt was quoted as saying "*Through the good times we don't need to change, we are making money on our farms and everything is ok. But when bad times hit, it really gets everyone looking over the fence*". The Ruwoldts were producing good crops throughout the droughts, when others were unable to establish crops.

The Kiley family was also looking to change after the evidence of erosion and indicated that "… *conventional farming methods were just unsustainable*". They began by reducing tillage and moving out of livestock, but it was the influence of farmers like Robert Ruwoldt and farmer agronomist Danny Conlan that convinced them to go further into full no-till, stubble retention and controlled traffic farming. The success of the change enabled the family to double their operation in the next ten years; a demonstration field day on their property in March 2013, attracted over 300 farmers. Terry Kiley was quoted as saying "*If we hadn't changed I'm sure we wouldn't have been able to expand*", making a powerful argument to other farmers considering change.

In adopting Conservation Agriculture farmers will often follow different paths in developing their research strategies, depending on their circumstances. The Missen family had what they described as "hostile subsoils and acidic topsoils". They embarked on a continual path of testing ideas to improve the performance of every single paddock. They gained great success from faba-beans (*Vicia faba*) which their neighbours called "failure beans" due to the high risk of the crop failing to produce a profitable yield. However, with no-till systems, the Missens were able to demonstrate reliable grain yields with the added benefit that biological nitrogen fixation provided a source of nitrogen for subsequent crops.

Continuing the plant nutrition theme, the Missens are evaluating variable rate application of fertilisers, based on plant and soil testing, resulting in reduced fertilizer cost on a yield basis. This example shows that experience of success encourages the process for more experimentation, and that early successes encourage farmers to explore progress in other areas; as Troy Missen suggests "*...has given me confidence to do things on my farm that aren't generally done in this area-and it's definitely paid off*".

Farmers have long realised that no one formula fits all conditions. Murnong Farms, at Inverleigh, west of Geelong, went to the northern drier areas to learn about no-till and Controlled Traffic Farming (CTF), and returned with strategies to test in their higher rainfall areas. These areas experience problems with high stubble amounts, and experiments were started with choppers that cut the trash and spread it evenly across the full width of the header. The great value they gained from CTF was that it allowed their fields to drain faster under their wetter conditions, without the risk of erosion. Manager Josh Walter indicated that "... *we had our fair share of problems. We have tried things that people have been doing up North and that just didn't work. So we have tweaked them until they would work here.*" They had to reduce the length of stubble lying on the ground because in high rainfall areas the machine moves around more on wet ground, and difficulties were encountered where the tines came into contact with long stubble during inter-row sowing. They shared their experience with 60 farmers at a local field day indicating that their average yield for wheat increased from 3.5 to 6 t ha^{-1} over 4 years, with some fields producing up to 8 t ha^{-1}; canola yields increased from 1.2 to 2.6 t ha^{-1}.

Similarly, the Bell family were influenced by farmers like Robert Ruwoldt, Peter Walsh and their agronomist Andrew Newall. They made improvements to the header's straw choppers to minimise the higher chaff loads. As a result, they were able to improve their drought preparedness and they have now moved into Precision Agriculture. The Rethus family began conservation farming in 1982 with a focus on soil health parameters. They saw value in stubble mulching, but had significant problems managing the higher stubble loads. As a consequence, they are "... *still playing around with seed boots to get the seed to the exact spot we want it*". The Plant family were later adopters, taking up no-till in 2007, but since then have forged ahead, experimenting with a range of varieties. The young generation, Brad Plant, has quickly adapted to Precision Agriculture indicating "*There are more technological advancements happening in agriculture now and I like to see that, being younger and generation Y*".

A common theme is that farmers are not waiting passively for solutions to be offered. Rather, they see a need for change and go looking for answers. For example, Wayne Robbins "*I'm one for asking questions and there is usually someone who has the answer*". If these farmers perceive a potential benefit they will try an idea and expect to make some modifications to get it right. Once having achieved some success, they are happy to share the technical details with their neighbours. This process of diffusing technology among farmers provides a greater level of tested technical details and increases confidence, resulting in more rapid adoption. Farmers are just as concerned about what doesn't work as what does work.

3. 2 *South Australia* (*farmer/advisor to farmer*)

The South Australian example illustrates a not unusual situation where the farm advisor is also a farmer. This dual role provides an interesting capacity since as an advisor there is access to technical data and other core research outputs, and as a farmer the research can be evaluated in a real life context. Additionally, advisors work with a range of farmers and see a range of conditions, and as a farmer they bring strong credibility to adoption (Johnson, 2012).

Nick Hillier is both a farmer and crop advisor in South Australia. He saw the potential of no-till in the early years "*We could see the degradation of the soil. My father wanted to retain more and more stubble, so we started developing machinery and new ways*". He invested in a disc seeder and learned about stubble management through trial and error on his farm. He had issues with "hair-pinning" in the first two years (when long crop stubble is tightly bent around disc implements and pushed into the soil, disrupting seed placement and eventually blocking machinery), and now leaves more standing stubble by cutting higher, thereby minimising the amount of inter-row stubble on the soil surface. In the dry years he was getting excellent early germination due to the stored subsoil moisture. Nick can rely on this personal problem solving experience to assist him in his role as advisor to 35 farmer clients.

In a variation in this combined role, there are crop contractors that are both farmers and advisors. Often they are smaller or ex-farmers who can amortise their new machinery cost by offering a contracting service in their local area. Nathan Craig retained his family's disc seeder after the property was sold, to operate as a contracting business and farm manager. In that role, he has access to the farm he manages and a range of contracting clients.

This provides the opportunity to test ideas and refine them into working systems. As a contractor, he sees different conditions and how well things work over a number of farms. Farmers often rely on their contractor's advice as someone who has practical, in-field experience with farm machinery.

3. 3 *Western Australia* (*mixed farming examples*)

The examples from Western Australia illustrate the different farmer approaches to the challenge of integrating sheep into CA cropping systems (Celenza, 2012). Integration of livestock and cropping enterprises presents specific challenges and opportunities. For crop or livestock scientists, it is difficult to integrate their research as they come from different disciplines and backgrounds, and are funded from separate commodity based research organisations. In contrast, for mixed enterprise farmers, it's a natural process to observe how new technology is integrated into the combined system. For farmer, Robert Egerton-Warburton, he sees a successful synergy from integrating cropping and livestock. He minimises his weed resistance by collecting his harvest chaff to feed to his sheep. "*We found it really works well as a weed management and livestock management tool; its great placing chaff in piles for easy access by stock and a great tool for decreasing weed burden. For us, chaff carting has a 60% grazing and 40% weed control benefit*". They also use sheep to graze the weeds in their crops inter-row to eliminate wild radish, and have experimented with various stocking rates from 12 to 20 Dry Sheep Equivalent (DSE), and settled on 17 as the most economical and easiest to manage.

The Yates family are another mixed enterprise farm running sheep and cropping. They accept the negative impacts of sheep on soil quality, but see the value of livestock as part of an integrated weed control program. They have also tried various stubble management programs to limit the damage by livestock, now cutting higher to always leave more standing stubble in the paddock. These innovative farmers operate on the principle that farmers are free to adopt or reject a practice only after deciding if that practice is "right for us". They appreciate that not only do all farms have specific bio-physical environments, but also that farmers themselves have different knowledge, skills and aspirations. Farmers are free to test, modify or reject what is being demonstrated.

3. 4 *New South Wales* (*farmers as field researchers*)

Farmers can also use modern research tools to make a compelling case for other farmers to better understand their farm resources. The Nicholson family, in the Grenfell area, initiated a program to restore the damage caused by 100 years of European style conventional farming (Conservation Agriculture and No-Till Farmers Association, 2011). Their typical soil test in 2001 showed phosphorus levels of 2.5 mg kg^{-1}, nitrogen levels of 4.6 mg kg^{-1}, surface sodium levels of 8.5%, organic carbon of 0.6% and a soil pH of 7. 1. They set to work introducing no-till, stubble retention and gypsum application. They destocked in 2005, and introduced an integrated weed management program to manage herbicide resistant weed populations. Six years later the soil fertility from the same site had improved, with phosphorus rising to 20.7 mg kg^{-1}, nitrogen to 18.4 mg kg^{-1}, sodium had fallen to 3%, organic carbon had risen to 1.4%, and soil pH had stabilised at 5.1. Steve Nicholson explains that he likes to see his soil's pH around 5 to 6 because his soils are sodic: he maintains that "*... as more carbon is added to our soils, we will see the pH creep up*". Monitoring soil fertility provides some confidence in their system, but what is more convincing to visiting farmers was the consistently high yielding crops they could see in the paddock, and the extra moisture from the demonstration soil pit. Farmers could associate the soil analysis reports to what it actually means in crop yield and profits, and also gained valuable practical knowledge in soil science.

Al Payne is another combined commercial agronomist and farmer that has turned his farm into a pseudo research station. As with many farmers, he faced considerable challenges to improve moisture retention, and manage weeds, diseases and pests. His agronomy network, with a range of on-farm variety and chemistry trials, helped him stay on top of herbicide resistant weeds. He maintains that "*The best learning platforms are industry groups. Being part of these groups helps to identify where the problems might be and hopefully avoid them*".

Some farmers are also researchers in their own right. For example, in the Williams family, Anne is doing her PhD at the University of New England and is testing a number of interventions on the family farm. She did an economic analysis comparing how they can improve their crop residue levels using cover cropping as an alternative practice.

These linkages within the agricultural community indicate that farmers are a heterogeneous group, and also active members of a community network. Although the innovations of individual farmers are significant, it is the farmer network that gives it strength and credence. Farmers add value to the research conducted by research institutions by testing, adapting, and disseminating technology.

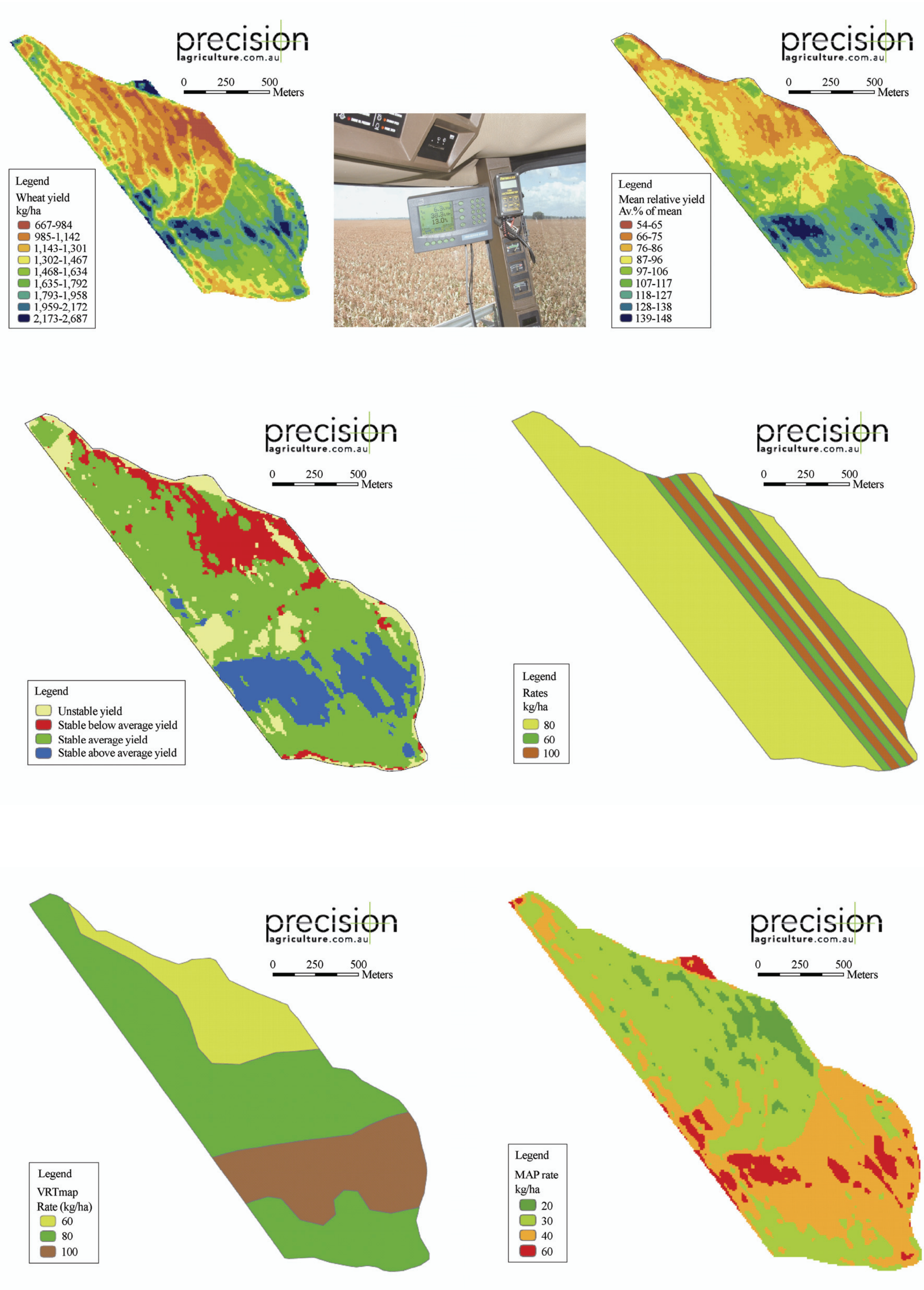

Fig. 4 Yield data collected at harvest (top left) from in cabin yield monitor (top centre) can be averaged over several years to provide a normalised yield map of the field (top right)

[Red-orange low yields (<1. 5 t ha^{-1}), blue high yields (>2 t ha^{-1}). Annual variability in yield (middle left) can be analysed to predict stable areas of "below average", "average" and "above average" yields. A range of fertiliser rates can be applied in trial strips (middle right) to determine crop yield response. Based on the trial results, maps prescribing variable fertiliser rates can be deployed as a simple three zone system (bottom left) or a more complex system that delivers variable rates of fertiliser on a finer scale (bottom right). (Source: T. Neale, Precisionagriculture. com. au, used with permission)]

3.5 *Queensland* (*specialist agronomist and on-farm trials*)

In Queensland, farmers are experimenting with Global Navigation Satellite Systems (GNSS) in farm management, using recent developments in technology that have considerably simplified the process (Spaans, 2000; Neale, 2013). Specialist precision agriculture consulting firms that combine information technology with agronomy are assisting farmers assess how this technology can improve efficiency (Cook and Bramley, 2000; Mayfield and Trengrove, 2009). Traditionally, fields have been treated uniformly from a machine operation perspective, ignoring soil type, moisture conditions or weed populations, but with Precision Agriculture the farmer has the option to integrate proximal and remote sensors to deploy farm operation more accurately and at a finer scale. These technologies enable farmers to more efficiently manage increasingly expensive inputs such as fertilisers and herbicides (Rochecouste, 2009), including better control on the speed of operation and reduced operator fatigue. Negative environmental impacts such as nitrogen emissions, nitrate leaching, and soil acidification, can also be minimised by reducing fertiliser inputs to low yielding areas (Hochman, et al., 2013).

The farm economy is characterised by increasing input costs and farmers are constantly searching for small gains in the efficiency of their operations. Farmers have always been aware of within paddock variability in soils and crop growth, but until recently it was inconceivable that crop inputs (e. g. fertilisers) could be delivered with variable rates depending on crop demand. Crop yield mapping has brought this variation into sharp detail, and now variable rate technology is allowing farmers to vary crop inputs leading to increased efficiency, higher profits, and reduced environmental impacts. The case study from Queensland illustrates the development and application of Precision Agriculture on farm, and highlights how this technology has created new modes of research partnerships between farmers, consultants, and scientists. Variability in crop yield from any field can be obtained using on-board yield monitoring to capture variation across the field as the crop is harvested (Fig. 4, top left). Annual data can be analysed separately, or averaged over multiple years (Fig. 4, top right). This variation can be explored further for the likely soil factors associated with this response. The degree of variability in grain yield can be analysed and fertiliser rate experiments can be imposed in the farmer's field using the farmer's equipment (Fig. 4, middle right). Grain yield response to the different fertiliser rates can be monitored at harvest time and results analysed to prescribe variable rate fertiliser delivery for subsequent crops (Fig. 4, bottom).

4 Creating conditions for farmer innovation to flourish

The preceding examples of farmer innovation reveal a diversity of applications and developing networks of relationships. Some interventions involve traditional research and development providers, but more often than not, there are new actors, particularly farmers themselves, playing a central role in the process of innovation. Fig. 5 illustrates the various roles played by farmers in the development and refinement of Conservation Agriculture, and provides a framework for analysing the strengths and weaknesses of the various actors in the innovation system.

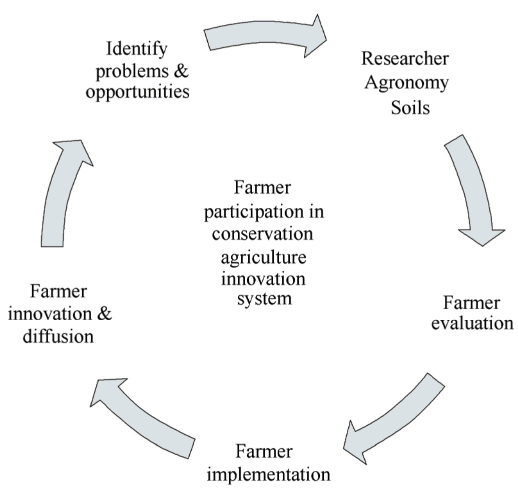

Fig. 5 Conceptual model of the Australian Conservation Agriculture innovation system.

Central to this approach is that institutionalised research and development (Step 1) is just one of several steps in the innovation system. Outputs (new technology, management practices, knowledge and understanding) from the research sector may or may not be evaluated by farmers (Step 2), depending on the relevance of the research to the needs of the farmer. During the process of evaluation (with or without formal research partnership), early adopters communicate their experience to other interested farmers at field days and other events. If attractive, a growing number of farmers begin to implement the innovation on their farm (Step 3), adapting the technology to better suit their conditions, resulting in localised versions of the original research output. By a process of farmer-to-farmer communication and learning, the innovation is scaled out (Step 4), with farmers becoming increasingly involved in diffusion of innovation. The loop is closed (Step 5) with farmer identification of new problems and opportunities which may be addressed as research priorities by the research sector. And so, the innovation system proceeds in a continual cycle of generation of new technology (ideas, etc.), evaluation, implementation, diffusion, and identification of new research opportunities.

Researchers, farmers, and consultants all play a role in the innovation process, each bringing different strengths to the system. In the preceding examples, some of the strengths of farmer innovation are revealed:

- *Site specific*. New technology is evaluated under local conditions (soils, climate, weeds, etc.). Farmers are able to test and adapt technology under their constraints, and neighbouring farmers can relate to the similar settings.
- *Integration*. Farmers can integrate specific component technology into their production systems. For example, integration of crops and livestock, and evaluating innovation in terms of the financial bottom line.
- *Incremental.* While CA is often viewed correctly as a transformational change in farming system, farmers often adopt and adapt elements of the package in an incremental fashion. It has taken 40 years for the overnight success of CA in Australia!
- *Scale*. Farmers relate more easily to an innovation if the scale of intervention relates to the scale of their operations. Scale relates to size of machinery, area of individual fields, and annual turnover of the enterprise. In a different sense, scale also relates to the number of individual farmers in an industry and the effectiveness of farmer-to-farmer learning.
- *One-size-does-not-fit-all*. Farmers are free to adopt or reject innovations depending on their financial and other lifestyle aspirations. For example, it is not unusual for neighbouring farmers to have very different enterprise mixes.
- *Effective communication*. Farmer-to-farmer communication ensures key messages are delivered using appropriate language, including appropriate communication of risk, complexity and uncertainty.

Innovation in farming systems, CA being a prime example, highlights the crucial necessity of farmer involvement in the innovation process. At a superficial level, Conservation Agriculture may appear as a simple change in crop establishment method, but in reality it is much more than this, with profound implications for biology, economics, and even some social elements of farming. For example, a shift to CA increases the amount of soil water available for crop transpiration, pest, disease and weed dynamics are profoundly altered, and plant nutrient availability changes. From an economic viewpoint, CA improves farm operating budgets, while at the same time requiring large capital investments in new equipment, and demanding more sophisticated financial and land management skills. CA also has implications for social relations, for example, reducing the amount of time farmers spend driving tractors, with implications for family relationships. Finally, CA is a knowledge intensive system of farming, requiring farmers to master not only a range of constantly evolving technologies, but also to take a wider perspective of their farming operations, requiring integrative analysis and skills. Largely because of the complex set of changes put in play with CA, it is not an innovation well suited to reductionist scientific study. Due to the systemic nature of change resulting from a shift to CA, it is better suited to farmer experimentation at the farm scale.

The future of CA in Australia continues to evolve, with new technology and new actors (researchers, farmers and consultants) contributing to the innovation system. No-till farmer organisations are at the forefront of implementation and diffusion of CA. A sample of current research, development and education projects initiated and implemented by Australian no-till farmers' associations (Table 1) provides an indication of their interests, priorities, and funding sources.

The projects listed in Table 1 provide an indication of the diversity of projects run by Australian no-till farmer associations. It is not a comprehensive list and the reader is referred to the individual web sites for further details. As expected, practical topics feature in the list, and there is an emphasis on education, communication, and diffusion of knowledge. There are also several production research orientated projects, seeking further improvements in WUE, nutrient use, and stubble management. Several projects address societal concerns with the sustainability of farming. The projects also reveal a diverse range of funding sources, including government and public-private partnerships. These research partnerships will continue to grow in the future as researchers seek the relevance provided by farmer associations, and the farmer associations seek the confidence to change provided by scientific rigour.

There are many other examples of innovation where farmers are playing a critical role. Some key topics include; making better use of climate data to manage variability in the weather, incorporating crop simulation model output into crop management decisions, exploring the role of robotics in broad acre cropping (e. g. application of herbicide to weeds), trialling market based instruments for environmental services (e. g. payment for sequestering carbon), and a host of other potential technologies and farming systems. An additional aspect of farmer innovation is the importance of human capacity, and the need for continued investment in human capacity to enable farmer innovation, and continued investment in, and promotion of farmer education. Equally important is the system of informal education and knowledge sharing. Younger farmers have enthusiastically embraced social media, such as Twitter and Facebook, and a range of information websites, blogs and YouTube videos have proliferated. As with society in general, the internet information revolution is transforming farmer to farmer communication, and partially overcoming traditional barriers of isolation and distance associated with rural communities.

5 Conclusions

The diversity of farmer experience with innovation reveals a complex set of motivating factors. Policy settings that empower farmers to play a more active role in the innovation system have been significant. Economic settings that provide incentives for achieving greater efficiency in converting inputs to agricultural outputs are also important. Access to technology, data and new knowledge is essential, as is the integration of these data and knowledge into integrated farm management systems. This is a complex challenge, and farmers are responding with a range of knowledge management innovations, greater use of consultants, formation of farmer groups, and greater use of social media. Maintaining and seeking new relationships and partnerships is a feature.

The farmer stories reveal several preconditions that are significant in creating an enabling environment where farmer innovation can flourish. These include:

- *A felt need for change*. The long and gradual decline in farmers' Terms of Trade, combined with low levels of government subsidies, has driven a relentless search for more efficient production systems. CA meets this objective by producing more grain per mm of crop water use. Drought conditions often increase farmer interest in CA.
- *Farming has become more complex*. The shift from a production focus to a sustainability focus has been central to the attractiveness of CA. Under CA, yield increases are compatible with reduced environmental damage. In this sense CA is a prime example of sustainable intensification.
- *Creating space for innovation*. The demise in state agricultural extension services in Australia created a gap in knowledge to which farmers were quick to respond. Crop monitoring groups evolved into local farmer groups, and then regional and issue focussed groups. Paradoxically, in order to promote farmer innovation, state R&D agencies may need to 'pull back' from some traditional modes of operation and refocus in supportive roles.
- *Continual evolution*. The process of innovation is constantly changing; in the context of CA in Australia, the innovation process itself has become an innovation. For example, the emergence of no-till farmer organisations has changed the way farming systems research is conducted.
- *Convergence and integration*. New technologies become applied in ways not envisaged at the time of their invention. The process of farmer innovation leads to unforeseen applications and benefits, for example, the rapidly evolving domain of precision agriculture.

The Australian story of farmer innovation in CA reveals a complex interplay of policy, economics, science, and farming. To claim that the 40-year process was carefully planned would be misleading, but this does not deny key policy decisions which contributed to an environment where farmer innovation could flourish. A key policy development was the creation of Rural Research and Development Corporations in the mid 1980s. These corporations gave voice to farmers and ensured research was relevant to farmers' needs. Equally important is the Australian position on free trade, forcing farmers to compete on world commodity markets with little government support. The impact on farm businesses is a relentless pursuit of efficiency, and CA addresses several economic and environmental imperatives. The withdrawal of traditional agricultural extension agencies has been a catalyst for farmer based R&D organisations. Whether these farmer organisations could have flourished to such an extent if government services had been maintained is doubtful. The availability of new technology (varieties, herbicides, machinery, and most recently precision agriculture) has created new opportunities, and farmers have been adept at integrating these technologies into farming systems. Lastly, the inventiveness and tenacity of Australian farmers in the face of adversity cannot be overestimated.

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